Valley Networks And The Fingerprints Of Martian Wet Based Glaciation.

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Introduction: Thousands of valley networks incise the southern hemispheric highlands of Mars, standing as evidence that liquid water sculpted the surface of Mars billions of years ago [1, 2, 3]. This scenario contrasts starkly with the current climate of Mars, with a hydrological cycle controlled by sublimation and precipitation of water ice mainly in the polar regions [4], and thousands of ice deposits in the mid-latitudes [5]. The motion and deformation rates of these deposits is negligible, strongly hindered due to the extremely low temperatures, high dust contents, and cold-based conditions (base of the ice is frozen).

A problematic transient lies in between: It is reasonable to expect that the climatic transition between surface liquid water stability and the current cold-based ice masses produced large-scale water-ice interactions [6]. And whereas ice masses with basal meltwater accumulation (wet-based) produce some of the most arresting and large-scale erosional landscapes on Earth (Figure 1, panels 2 and 3), these same morphologies are notoriously rare on Mars. This problematic lack of wet-based glacial erosion signs has historically led to the interpretation that Martian glaciation was cold-based [6, 7]. However, the discovery of extensive eskers and esker fields in the Dorsa Argentea Formation [8], as well as examples dating from the Amazonian period in the mid-latitudes [9] challenge the hypothesis that Martian ice masses were always frozen to the ground. The presence of subglacial water, possibly into the Amazonian period, poses important implications for the history of climate, hydrology, and the presence of habitable environments well after the early Mars period.

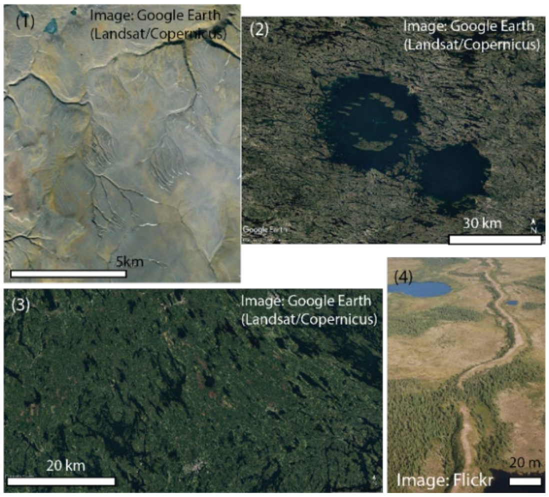

Fig 1. Fingerprints of wet-based glaciation on Earth. (1) Subglacial channels (Nunavut). (2) Mega-scale lineations (Quebec). (2) Scouring marks and striae (Finland). (4) Esker (Labrador). Image sources indicated in each panel.

Hypotheses: The fingerprints of wet-based glaciation differ on Earth and Mars. (1) The lower Martian gravity modifies the dynamics of wet-based glaciers, favoring the emplacement of efficient subglacial drainage conduits, reducing water availability at the base, and limiting ice sliding motion [10]; (2) the morphology of certain valley networks is consistent with observations of subglacial channels in the Canadian Arctic Archipelago [11, 12], which are the erosional fingerprints of the subglacial drainage system. Consequently, wet-based glaciation fingerprints on Mars may be largely limited to channels and eskers (figure 1, panels 1 and 4).

Framework: Water accumulated beneath ice masses is confined under large pressures and pressure gradients, which drive it away from thick ice towards the ice margin. When no efficient drainage exists, basal water accumulates in pockets and cavities, where water pressure builds up and partially opposes ice pressure, lubricating the ice mass. This process results in ice acceleration, which slides as a block under its own weight (Figure 2). The process of glacial sliding is the most common response on Earth to water accumulation at the base and leads to highly directional scoured landscapes (Figure 1, panels 2 and 3).

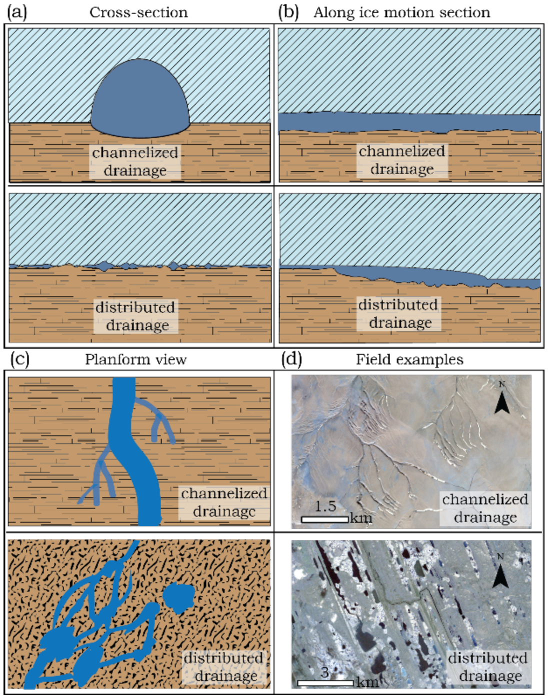

Fig. 2. The drainage of wet-based ice sheets. Upper a,b,c panels show subglacial channels and efficient basal drainage, and their landscape expression (d). Bottom a,b,c panels show inefficient, distributed drainage by cavities, and their landscape expression (d).

The opposite occurs when basal meltwater drains efficiently through subglacial channel networks. The resulting low water pressure cannot produce ice lubrication, which slows or halts ice sliding. The fingerprints of channelized drainage consist on subglacial channels etched on the ground, intertwined with depositional landforms such as eskers. These features may or may not be associated with signs of sliding, scouring, moraines, etc. [11].

The feedback that controls sliding velocity as a function of effective pressure (ice overburden minus basal water pressure) and subglacial drainage scenario (cavities/ channels) is controlled by a competition between sliding velocity [10,13,14] and drainage system evolution [10, 14].

Results: We adapted the glacial hydrology physical framework existing for Earth [10,13] to Mars to interrogate the Earth-Mars difference in ice sliding motion produced by the lower Martian surface gravity. We present the results in figure 3 [14]. Comparing Earth (blue) and Mars (red), we notice that sliding rates are a factor ~20-90 slower on Mars when the effects of glacial hydrology and drainage are considered. We also find that whereas Earth's gravity favors less efficient drainage (blue arrow), Mars gravity favors the establishment of channels (red arrow) [14].

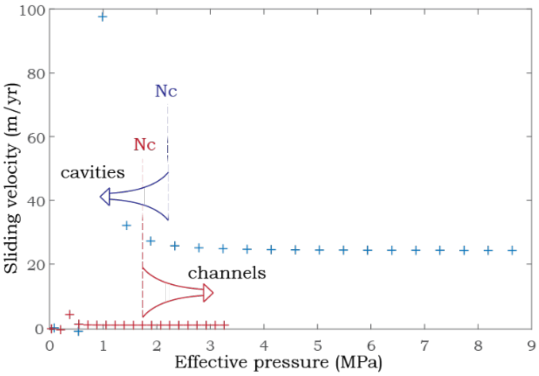

Fig. 3: Results showing glacial sliding velocity on Earth (blue crosses) and Mars (red crosses) vs. effective pressure (ice minus water pressure).

Discussion: Glacial erosion scales with ice sliding velocity to a power 1-2 [13,15], so that erosion rates on Mars would be ~10^2-10^4 smaller than Earth given our results. Erosion and deposition would thus occur in subglacial channels on Mars, leading to Martian glacial landscapes similar to those of the high Arctic [12,14].

Rivers and subglacial channels are similar (figure 4) [11,12]. To distinguish subglacial erosion, we search for: undulating sections (uphill downflow segments); a near-constant downstream width; absence of inner channels; absence of interfluve dissection between networks; depositional regimes including inverted ridges (eskers) and terminal fans; trapezoidal cross-sections, etc. It is interesting to consider that these characteristics may explain puzzling morphologies observed in the Martian valley networks that are hardly consistent with riverine erosion [1, 3], as well as pose a valid analogue to their planform morphology (figure 4). Based on the similar characteristics between terrestrial subglacial channels and Martian valleys, some valley networks could have formed under ice sheets [12,14].

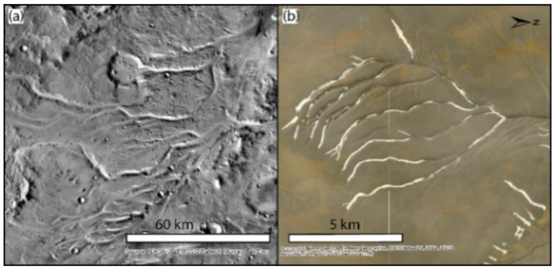

Figure 4: Planform similarity between Vedra valles (panel a, image center is 18°49'2.80"N, 55°13'12.46"W) and subglacial channel networks (b) in Devon Island (image center is 75°17'12.27"N, 89° 8'44.64"W).

Conclusions: To understand the lack of large scale wet-based glacial erosional features on Mars, we use the theoretical framework developed for glacial hydrology on Earth. We show that glacial sliding is heavily inhibited on Mars (20-90 times slower), owing to its lower gravity, and instead a stable system of subglacial channel networks is emplaced. Comparing the morphology of subglacial channels on Earth (analogues from Devon Island) with Martian examples, we find similarities in planform, longitudinal profile characteristics (undulations), and cross-sectional shape and evolution. We conclude that the fingerprints of wet-based glaciation may be fundamentally different on Mars, that care should be taken using Earth-Mars glacial analogues, and that some valley networks may have formed beneath ice sheets.

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